EDGEWOOD CHEMICAL BIOLOGICAL CENTER
U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
Aberdeen Proving Ground, MD 21010-5424

ECBC-TR-1418

RESPIRATORY PROTECTION PERFORMANCE: IMPACT OF HELMET INTEGRATION

Daniel J. Barker
Corey M. Grove

RESEARCH AND TECHNOLOGY DIRECTORATE

Douglas E. Wilke
Steven A. Yurechko

ENGINEERING DIRECTORATE

September 2016

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
XX-09-2016	Final	Sep 2015 – Mar 2016

4. TITLE AND SUBTITLE
Respiratory Protection Performance: Impact of Helmet Integration

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Barker, Daniel J.; Grove, Corey M.; Wilke, Douglas E.; and Yurechko, Steven A.

5d. PROJECT NUMBER
BA16PHM604

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Director, ECBC, ATTN: RDCB-DRP-P, APG, MD 21010-5424

8. PERFORMING ORGANIZATION REPORT NUMBER
ECBC-TR-1418

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Threat Reduction Agency, Joint Science and Technology Office,
8725 John J. Kingman Road, Fort Belvoir, VA 22060-6201

10. SPONSOR/MONITOR'S ACRONYM(S)
DTRA JSTO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In this study, we evaluated the impact of the concept of an integrated helmet respirator on respiratory protection effectiveness as compared with a helmet and respirator worn in a traditional nonintegrated manner. The integrated system allows a wearer to use the respirator without requiring removal of the ballistic protective helmet. We found that there were no significant differences for overall protection factor (PF) results or specific exercise PF results between the integrated and nonintegrated systems, regardless of night vision goggle (NVG) usage. In addition, NVG usage did not result in significant differences within the integrated or nonintegrated configurations. Further investigation is needed to demonstrate that integrated helmet respirator systems that use ballistic materials with greater mass can achieve similar levels of respiratory protection.

15. SUBJECT TERMS

Respiratory protection	Protection factor (PF)	Integration system
Bizygomatic breadth	Menton–sellion length	Night vision goggle (NVG)
Nonintegration system		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Renu B. Rastogi
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	UU	22	(410) 436-7545

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PREFACE

The work described in this report was authorized under project number BA16PHM604: Full Spectrum Respiratory Protection Technology. This work was started in September 2015 and completed in March 2016.

In conducting the research described in this report, the investigators adhered to Army Regulation 70-25, *Research and Development Use of Volunteers as Subjects of Research;* 3 July 1974, as promulgated by the Office of the Surgeon General, Department of the Army. The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for public release.

Acknowledgments

The authors would like to thank all test participants for volunteering their time and displaying patience in the course of the numerous test iterations.

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RESPIRATORY PROTECTION PERFORMANCE: IMPACT OF HELMET INTEGRATION

1. INTRODUCTION

Multiple operational scenarios require that warfighters or tactical law enforcement personnel concurrently wear respiratory and ballistic protective equipment. Current personal protective equipment (PPE) relies on layering head-borne PPE subsystems (e.g., respirators, chemical protective hoods, communications devices, and ballistic helmets). The large majority of these systems were developed independently and are not integrated. This project evaluated a prototype integrated respirator helmet system.[1]

The objective of this effort was to determine the respiratory protection impact of integrating the helmet and respirator into one head-borne system. This system would allow a wearer to don the respirator without requiring removal of the protective helmet.

2. METHODS

2.1 Test Participants

Seven volunteers (6 males and 1 female) aged 35.9 ± 6.6 years (mean ± standard deviation [SD]) participated in this study. All of the volunteers were civilians employed at the U.S. Army Edgewood Chemical Biological Center (ECBC); the male volunteers were clean shaven. The bizygomatic breadth and menton–sellion length of each volunteer were measured. The volunteer facial anthropometric information is provided in Table 1.

Table 1. Volunteer Anthropometrics

Volunteer No.	Gender	Bizygomatic Breadth (mm)	Menton–Sellion Length (mm)
1	Male	132	142
2	Male	114	138
3	Male	116	134
4	Male	117	139
5	Male	109	127
6	Female	112	126
7	Male	117	138

Each volunteer provided signed, informed consent and completed the Occupational Health and Safety Administration Regulation 29 CFR 1910.134 Respirator Medical Evaluation Questionnaire. Medical personnel from the Kirk U.S. Army Health Center (Aberdeen Proving Ground, MD) reviewed the completed questionnaires and cleared the volunteers for respirator wear and testing. The volunteers received instructions regarding the

performance of the physical tasks, which comprised the protection factor (PF) trials of the investigation.

2.2 Experimental Conditions

Integrated and nonintegrated systems were assessed. Both system types consisted of an Ops-Core (Boston, MA) future assault shell technology base jump helmet and an Avon Protection (Belcamp, MD) C50 respirator. The volunteers wore the respirator and helmet configuration along with comfortable clothing of their choice for the trials. To assess the potential impact of helmet-borne weight, the integrated and nonintegrated systems were tested with and without concurrently worn AN-PVS/7 (Northrup Grumman, West Falls Church, VA) night vision goggles (NVGs). Table 2 outlines all of the experimental configurations evaluated during this effort. The C50 respirator was assessed in a negative-pressure airflow configuration. The presentation of the experimental configurations was randomized across trials.

Table 2. Experimental Configurations

Helmet/Mask System	AN/PVS-7 NVGs Worn
Integrated	Yes
Integrated	No
Nonintegrated	Yes
Nonintegrated	No

The integrated system was developed through a partnership with Battelle Memorial Institute (Columbus, OH) and Priority Designs, Inc. (Columbus, OH). Design features were built into the helmet and the respirator so that the mask could be worn without removing the helmet. A description of the design features and associated donning methods are included in Figures 1–3, but the model that is shown was not a study volunteer.

Figure 1. Step 1: Integrated system donning procedures. The volunteer put on the helmet first but left the chin strap detached. A forehead latch tab built into the C50 mask was guided into position in a forehead latch mechanism that was built into the helmet.

Figure 2. Step 2: Integrated system donning procedures. Next, the volunteer located the molded loops on the temple area fasteners and pulled them forward into position against elastic tension. Magnets within this fastener hardware were used to help guide the fastener to the receiver located on the mask.

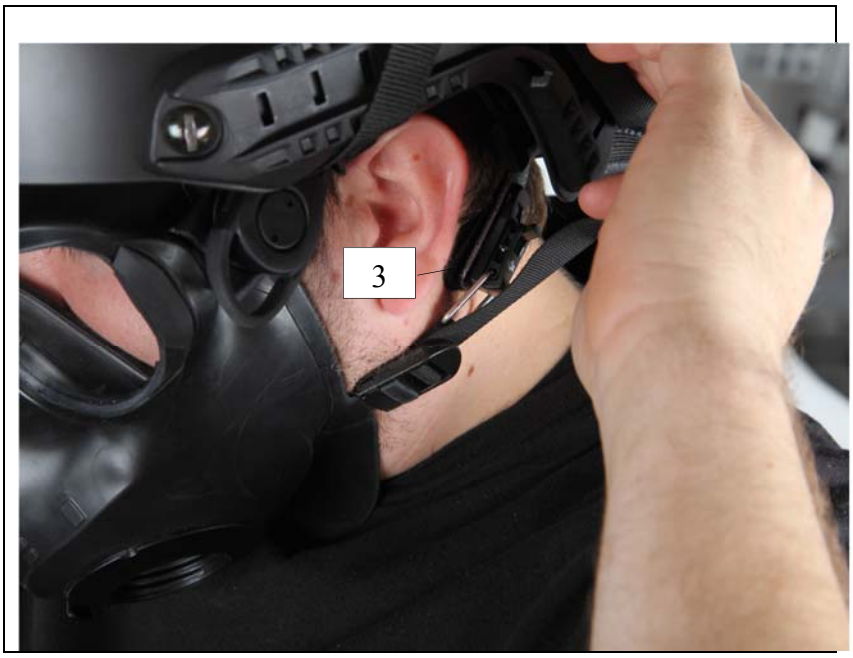

Figure 3. Step 3: Integrated system donning procedures. At the jawline, a modified Fidlock buckle (Lowy Enterprises, Inc.; Rancho Dominguez, CA) attached to the mask used magnets to latch to a receiver on the helmet retention system. The tension on the strap was then adjusted to tighten the C50 respirator fit.

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2.3 Test Procedures

All testing took place at the ECBC Protection Factor Test Facility (PFTF). After a volunteer arrived at the PFTF, all requisite paperwork was administered, and the volunteer's facial anthropometric data were collected.

Test administrators trained the volunteers on how to put on and remove each piece of equipment properly. For the nonintegrated system, the C50 mask was put on first. The helmet was then donned, and the chin strap was connected behind the respirator peripheral seal at the neck. The integrated system was worn as shown in Figures 1–3.

During the development phase of the integrated system prototype, it became evident that the helmet chin strap stowage was problematic when the mask was attached. The strap could not be expanded to fit around the exterior of the mask and was not easily stowed. Additional effort beyond this integrated prototype is required to solve this chinstrap problem. However, for these tests, the chinstrap was simply detached and fastened onto the helmet shell with hook-and-pile fasteners for safekeeping. The volunteers subjectively reported that even without the chin strap, the helmet and mask felt secured to the head when the respirator was worn.

After the volunteers had put on the equipment, a 10 ft Tygon (Professional Plastics, Inc.; Fullerton, CA) sampling tube was attached to the C50 drinking tube using a

sampling adapter. All air sampling was pulled through the drinking tube of the C50 mask at a rate of 2.2 L/min. The inner drinking tube was removed to prevent blockage by the volunteer.

After the gear was donned and a sampling tube was attached, the test volunteers were escorted into the PF testing chamber. Once inside the chamber, the sampling tube was attached to another tube, which was connected to a laser photometer located outside of the chamber. The challenge aerosol in the chamber used for the laboratory respiratory protection level test was composed of 99% poly α-olephin. The challenge concentration fell between 30 and 40 mg/m^3, and the mass median aerodynamic diameter particle size was between 0.4 and 0.6 μm. The test chamber is capable of maintaining particle spatial uniformity within ±5% in the vicinity of the respirator being tested.

Once chamber system checks were completed, test trials were begun. The test volunteers were asked to sequentially perform each of the following exercises for 1 min at a time:

(1) normal breathing,
(2) deep breathing,
(3) moving head from side to side laterally (once/second),
(4) moving head up and down (once/second),
(5) reciting the "Rainbow" passage,
(6) sighting a mock rifle,
(7) touching the floor and reaching for the ceiling,
(8) on hands and knees, moving head left and right,
(9) facial expressions (yawning, frowning, smiling, and rotating chin), and
(10) normal breathing.

Completion of one set of these exercises constituted one trial. In all, four trials were conducted, one for each experimental configuration.

Each configuration performance was quantified in PF terms, which was calculated by determining the ratio of the challenge aerosol concentration to the in-mask aerosol concentration, as quantified by integrating the peak voltage output from the photometer over a time interval. PF_i, the PF for each individual exercise, was calculated using eq 1:

$$PF_i = \frac{\text{Challenge Concentration}}{\text{Inmask Concentration}} \quad (1)$$

Then, the PF_i for each trial was used to calculate an overall PF for a volunteer (PF_o) using eq 2:

$$PF_o = n\left(\sum_{i=1}^{n}\frac{1}{PF_i}\right)^{-1} \quad (2)$$

where n is the number of exercises. PF_o is affected the most by the smallest PF_i. Under the conditions of this test and the sensitivity of the photometer, the maximum PF that could be reported was 500,000.

2.4 Data Analysis

All PF data were log transformed (Log_{10}) for analysis. Analysis of variance was used to test for statistical significance of PF performance within and between experimental conditions. Appropriate post hoc analyses were applied to identify between conditional differences, if warranted. Statistical computations were performed using SigmaPlot 12 software and Predictive Analytics software, version 17.0 (Systat Software, Inc.; San Jose, CA). Statistical significance was accepted at the $p < 0.05$ level.

3. PF RESULTS

No significant differences were found for overall PF results or specific PF exercise results between the integrated and nonintegrated systems, regardless of NVG usage. In addition, NVG usage did not result in significant differences within the integrated or nonintegrated configurations. Figure 4 illustrates the average overall PF results across all 10 exercises for each configuration. Table 3 shows the average PF results for each exercise.

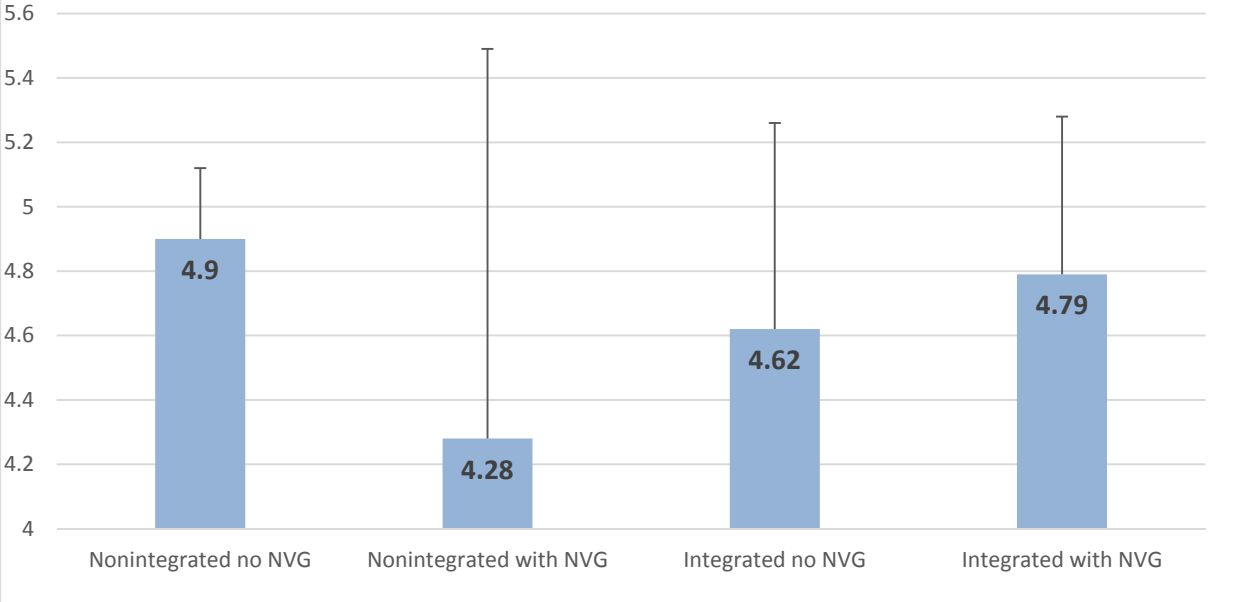

Figure 4. Average (±SD) overall PF Log_{10} results for all conditions.

Table 3. Average (±SD) PF Log_{10} Results by Exercise

Exercise	Test Bed System			
	Non-integrated without NVGs	Non-integrated with NVGs	Integrated without NVGs	Integrated with NVGs
Normal breathing (start of test)	4.97 ± 0.03	4.99 ± 0.01	4.98 ± 0.02	4.98 ± 0.02
Deep breathing	4.97 ± 0.05	4.99 ± 0.01	4.98 ± 0.04	4.99 ± 0.02
Move head from side to side	4.99 ± 0.01	4.96 ± 0.08	5.00 ± 0.00	4.94 ± 0.16
Move head up and down	4.98 ± 0.03	4.43 ± 1.31	4.91 ± 0.23	4.90 ± 0.27
Recite Rainbow passage	4.95 ± 0.06	4.29 ± 1.15	4.68 ± 0.78	4.78 ± 0.52
Sight the rifle	4.98 ± 0.02	4.19 ± 1.38	4.70 ± 0.58	4.98 ± 0.05
Reach for the ceiling and floor	4.94 ± 0.11	4.24 ± 1.28	4.46 ± 0.94	4.96 ± 0.10
On hands and knees, look left and right	4.90 ± 0.25	4.45 ± 1.07	4.90 ± 0.18	4.73 ± 0.64
Facial expressions	4.80 ± 0.53	4.71 ± 0.51	4.99 ± 0.02	4.68 ± 0.77
Normal breathing (end of test)	4.98 ± 0.04	4.74 ± 0.53	5.00 ± 0.00	4.86 ± 0.24

4. DISCUSSION

Although no statistically significant differences were found among the experimental configurations, some individual subject trial exercises had PF results that fell below the protection requirements set forth by the National Institute for Occupational Safety and Health (NIOSH) for chemical, biological, radiological, and nuclear air purifying respirators.[2] Twelve exercises resulted in PF scores below the NIOSH requirement of 2000 (Log_{10} = 3.30). Out of the 280 exercises completed over the course of this study, the following 12 resulted in PF scores below the NIOSH requirement:

- four occurred with the integrated configuration; two occurred with NVGs, and two occurred without NVGs; and
- eight occurred with the nonintegrated system, all of which occurred with NVGs.

Eleven of the 12 low scores occurred during trials with volunteer numbers 5 and 6. These two had facial anthropometrics that were smaller than the other volunteers. Because of prototyping resource constraints, the integrated system was created with only one size of respirator. The integrated prototype and nonintegrated system used medium facepieces. These two volunteers identified themselves as being able to obtain an adequate fit with medium or small respirators.

The strap length available for adjustment, which was provided at the jawline strap of the integrated system, was limited. It is likely that with more strap travel, volunteer numbers 5 and 6 would have achieved improved fit. Future prototypes will be built with increased strap travel to allow for greater tightening and improved accommodation of smaller faces.

5. CONCLUSIONS

This research concludes that high levels of respiratory protection are achievable with an integrated helmet respirator prototype. Further refinement is needed to demonstrate that integrated helmet respirator systems that use ballistic protective materials with greater mass can achieve similar levels of respiratory protection. Additional prototypes are planned to demonstrate this ballistic material usage and to investigate the potential ballistic performance impacts of integration. Further prototypes could also be used to better understand and improve sizing of the integrated solution.

LITERATURE CITED

1. Richardson, A.W.; Pettenski, T.A.; Brand, G.; Hofacre, K.C. *Development of Advanced CBRN Respirator Concepts*; CB-13-0630; Battelle Memorial Institute: Columbus, OH, 2015; UNCLASSIFIED Report.

2. National Institute for Occupational Safety and Health. *Statement of Standard for Chemical, Biological, Radiological, and Nuclear (CRBN) Full Facepiece Air Purifying Respirator (APR);* NIOSH: Washington, DC, 2003; UNCLASSIFIED Standard.

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ACRONYMS AND ABBREVIATIONS

ECBC	U.S. Army Edgewood Chemical Biological Center
Log_{10}	log transformed
NIOSH	National Institute for Occupational Safety and Health
NVG	night vision goggle
PF	protection factor
PF_i	protection factor for each individual exercise
PF_o	overall protection factor for a volunteer
PFTF	Protection Factor Test Facility
PPE	personal protective equipment
SD	standard deviation

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Barker, D.

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